SUPPORTING DOCUMENT D

TECHNICAL MEMORANDUM CH2MHILL

Upper Swift Creek Plan Total Phosphorus Loading Analysis for Planned Land Use Scenarios

PREPARED FOR: Chesterfield County

PREPARED BY: Tim Hare – CH2M HILL
Jamie Lynn Conner – CH2M HILL

COPIES: Dan Medina – CH2M HILL

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Executive Summary

Annual total phosphorus (TP) loads were calculated for four scenarios, testing different housing densities for the future Upper Swift Creek plan. In-lake phosphorus concentrations were predicted for each scenario. Load reductions to achieve the desired in-lake concentration of 0.05 milligrams per liter (mg/L) for total phosphorus were calculated for each scenario. The Planning Department's Preferred Alternative, Scenario B (2 dwelling units per acre) can be met using the 1999 management plan's best management practice (BMP) mix.

Introduction

In 1999, CH2M HILL and Timmons Group working with the County of Chesterfield, Virginia, developed the Watershed Management Master Plan and Maintenance Program for the Swift Creek Reservoir Watershed (Management Plan). The Management Plan was developed in response to citizen and County staff concerns that future development in the

Swift Creek Reservoir watershed would lead to eutrophication and degraded water quality in the reservoir.

The Swift Creek Reservoir serves both as a drinking water supply and a recreational destination. Part of the Management Plan entailed using the P8 Urban Catchment Model (Walker, 1990; Walker, 2000) to determine the annual TP loads and flows from the reservoir's 10 tributary watersheds and from the areas that contributed direct runoff. The results of the P8 modeling effort were in turn used as input for a predictive model developed by K. H. Reckhow (Reckhow, 1989). The Reckhow Model was used to predict the mean TP concentration in the reservoir during the summer.

In 2004, CH2M HILL was contracted to update the P8 tributary models and the Reckhow Model based on current land use. In 2005, CH2M HILL and Timmons Group were tasked with evaluating four different land use scenarios in support of a revised Upper Swift Creek Plan. This technical memorandum (TM) discusses the steps to collect the required data, and evaluate the scenarios using the P8 and Reckhow models. The TM compares the results with those developed in 1999.

Land Use Scenario Formulation and Data Development

Land Use Scenario Formulation

The existing land use from 2004 was adopted as the base land use. Since the 2004 land use was based on tax records and current use, it provides an accurate portrait of the watershed. The County desired to model the impacts of four different scenarios on water quality. As was the case in 1999, each scenario's projected planned land use was based on the conversion of vacant land to another land use, typically residential. It was assumed that the planned land use for Powhatan County in the upper portion of the watershed would be the same as 1999. Each scenario would look at the following different residential densities:

- Scenario A – 2.2 dwelling units per acre (du/ac).
- Scenario B – 2 du/ac.
- Scenario C – 1.5 du/ac.
- Scenario D – 1.0 du/ac.

Scenario A uses the housing density from the 1999 study instead of the 2.0 du/ac adopted in 2000 in order to maintain continuity with the 1999 results. All four scenarios have identical non-residential land use.

Conversion of vacant parcels was guided by the geographic information system version of the County's development potential database. Two fields in this database were used to determine whether an individual parcel was to be converted. The first was the field LND_USE_03, which indicates the actual land use for a given parcel in 2003. All parcels with VACANT in the LND_USE_03 field were identified as candidates for conversion. The second key field was ZONE_03, the existing zoning for the parcel. Vacant parcels zoned "A" indicate parcels that are subject to future development, but no such development had been officially identified for the parcel.

The next step for the vacant Zone A parcels was to check the development potential database to determine whether the parcel was projected for residential or commercial development. If it was projected for commercial development, then the parcel was identified as commercial/light industrial (CLI). If the parcel was projected for residential development, then it was assigned the appropriate land use code based on the scenario's residential densities.

Vacant parcels that are zoned for any nonresidential category were projected to the corresponding land use. Residential land use was assigned to vacant parcels zoned for residential based on parcel size and the approved number of units.

Certain parcels in the database were designated by the Planning Department as Deferred Growth Area parcels. The Deferred Growth Area parcels all have a maximum housing density of 0.2 du/ac and are all greater than 4.5 acres. These parcels are located in 6 of the 11 contributing watersheds including:

- Blackman Creek
- Horsepen Creek/ Deep Creek
- Otterdale Creek
- Swift Creek
- Turkey Creek
- The direct runoff component, which corresponds to runoff directly reaching the reservoir

Methodology for Impervious Fraction Calculations

One of P8's input parameters is the impervious fraction for each subwatershed. Impervious fractions were assigned to most land use categories based on the 1999 and 2004 modeling efforts. Impervious fractions for the converted residential areas were assigned based on the values in Table 1.

TABLE 1
Impervious Fraction Revisions
Upper Swift Creek Plan Modeling Support

Scenario	Residential Density (du / ac)	Impervious Fraction
A	2.2 – 4.0	0.35
B	2.0	0.34
C	1.5	0.31
D	1.0	0.15
B, C, D Deferred Growth Areas	0.2	0.05

Additionally, the new land use (CLI) was assigned an impervious fraction of 0.90. Using the revised impervious fraction information, the impervious fractions were calculated for each subwatershed.

Watershed Modeling

P8 Modeling

The 11 P8 models (10 tributary and 1 direct runoff to the lake) developed for the 2004 existing land use were modified to reflect changes in land use according to each scenario. The only change to each model was an adjustment of the impervious fraction for each subwatershed to account for land use changes. The remaining data, including precipitation and temperature, were identical to those used in the previous modeling efforts in 1999 and 2004.

Table 2 compares the land use scenarios among the three modeling efforts (1999, 2004, and current). Included in the table is a description of each scenario's development.

TABLE 2
Scenario Summary
Upper Swift Creek Reservoir Watershed Management Plan

Modeling Scenario	Description
1999 Existing Land Use	Existing land use at the time of the original study.
2004 Existing Land Use	Land use updated to 2004 including existing BMPs.
1999 Projected Planned Land Use	Planned land use projected by the original study. Based on converting vacant land to 2.2 du/ac
2005 Scenario A Projected Planned Land Use	Planned land use projected by converting vacant land from 2004 Existing Land Use to 2.2 du/ac. Maintains continuity with 1999 study.
2005 Scenario B Projected Planned Land Use	Planned land use projected by converting vacant land from 2004 Existing Land Use to 2 du/ac, additional conversion of 4,079 acres to RR (Deferred Growth Areas).
2005 Scenario C Projected Planned Land Use	Planned land use projected by converting vacant land from 2004 Existing Land Use to 1.5 du/ac, additional conversion of 4,079 acres to RR.(Deferred Growth Areas)
2005 Scenario D Projected Planned Land Use	Planned land use projected by converting vacant land from 2004 Existing Land Use to 1 du/ac, additional conversion of 4,079 acres to RR.(Deferred Growth Areas)

Notes:

RR = rural residential

Table 3 summarizes the previous modeling efforts, breaking down by tributary watershed the TP annual loads calculated for the 1999 Existing Land Use, 2004 Existing Land Use, and the 1999 Projected Planned Land Use scenarios.

TABLE 3
Summary of Previously Modeled Total Phosphorus Annual Loads
Upper Swift Creek Reservoir Watershed Management Plan

Watershed	1999 Existing Land Use	2004 Existing Land Use	1999 Projected Planned Land Use
TP Annual Load (lb/yr)	12,189	14,547	43,508

The results of the tributary model runs for Scenarios A through D are summarized in Table 4. The total TP annual load for Scenario A is significantly greater than any of the other scenarios. The overall TP annual loads from Scenarios B and C are similar to each other and to the 1999 projected planned land use. Scenario D is 11 percent lower than the 1999 results. The annual loads by tributary watershed are shown in Figure 1.

It is clear that several watersheds are projected to experience denser development than what was anticipated in 1999. This effect can be seen where the annual load for Scenario A exceeds the annual load for the 1999 projected planned land use by 10 percent. This is the case with Turkey Creek, Otterdale Creek, Horsepen Creek/ Deep Creek, and the direct runoff component. The total annual flows generated by each scenario are similar. All four scenarios and the 1999 planned land use total flows fall within 3 percent of each other.

TABLE 4
Summary of Total Phosphorus Annual Loads and Flows by Scenario with Deferred Growth Areas
Upper Swift Creek Reservoir Watershed Management Plan

	Scenario A Projected Planned Land Use	Scenario B Projected Planned Land Use	Scenario C Projected Planned Land Use	Scenario D Projected Planned Land Use	1999 Projected Planned Land Use
Total TP Annual Load (lb/yr)	47,674	42,784	42,181	38,926	43,508
Total Annual Flows (ac-ft)	100,923	99,376	99,186	98,214	100,392

Reckhow Modeling

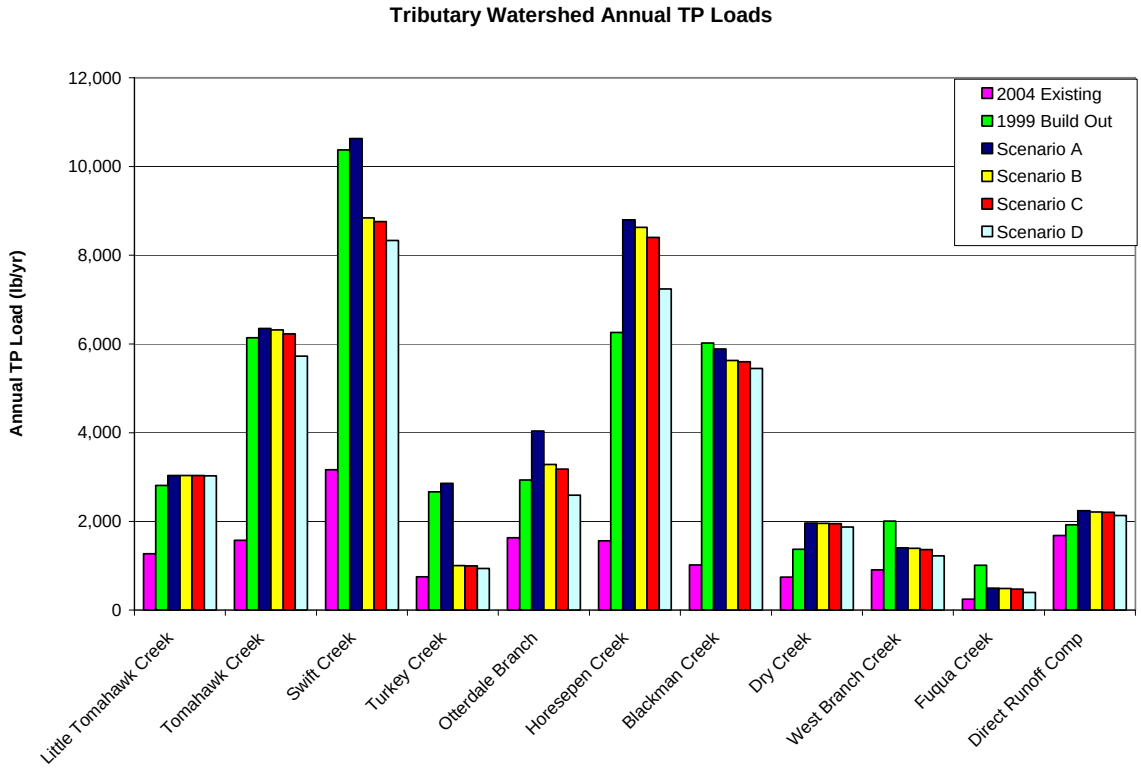
As in the two previous modeling efforts, the impact of the TP loads on Swift Creek Reservoir were projected by using one of Reckhow's empirical relationships for Southeastern U.S. reservoirs:

$$P = \frac{P_{in}}{1 + 3P_{in}^{0.53} T^{0.25} Z^{0.58}}$$

where:

P is the median summer in-lake TP concentration (mg/L)
P_{in} is the mean annual influent TP concentration (mg/L)
T is the hydraulic detention time (yr)
Z is the mean depth of the lake (m)

FIGURE 1
Summary of Total Phosphorous Annual Loads by Scenario
Upper Swift Creek Reservoir Watershed Management Plan

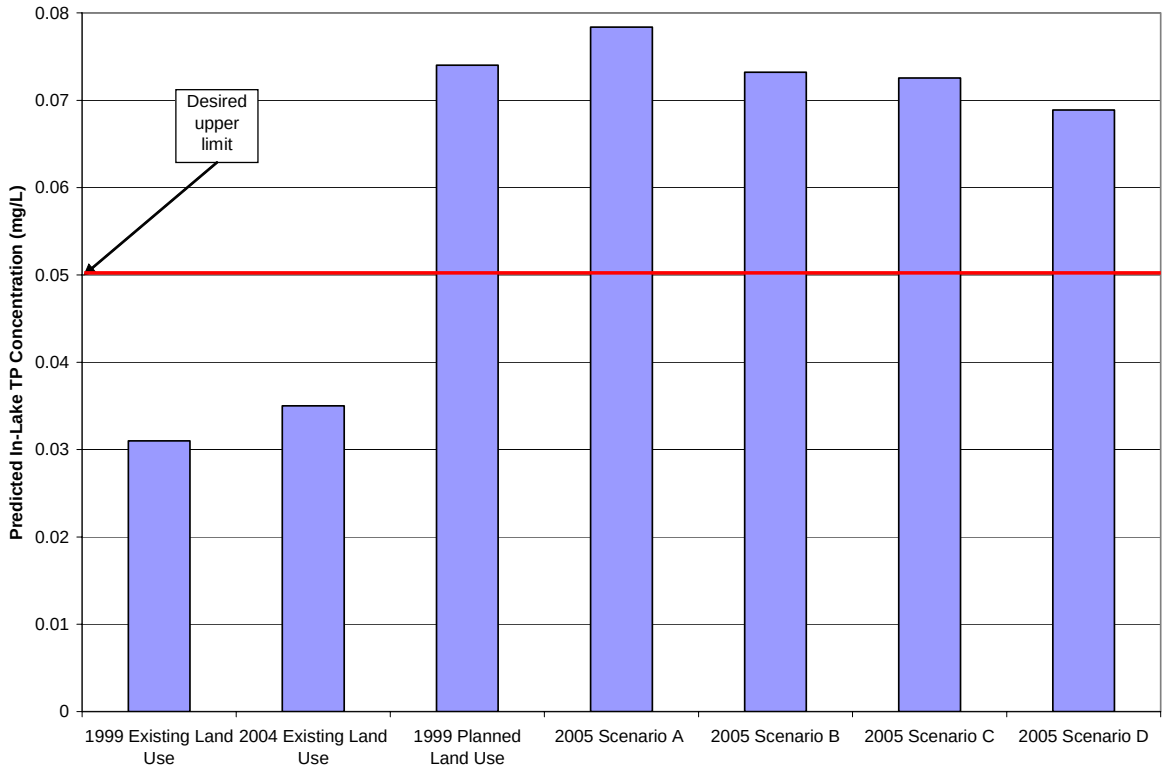


P_{in} was calculated by converting the TP annual load to kilograms per year (kg/yr) and dividing by the total annual flow converted to cubic meters per year (m^3/yr). The hydraulic detention time T, was calculated by dividing the reservoir volume by the annual flow in m^3/yr. Both the reservoir volume and average depth were assumed to be the same as those

used in the Management Plan. Reckhow Model results are displayed in Figure 2 and summarized in Appendix A.

All of the future scenarios are above the desired 0.05 mg/L limit for TP. In-lake concentrations greater than 0.05 mg/L are considered to be eutrophic, causing severe water quality degradation in the reservoir. Scenario A results in a higher in-lake TP concentration than the 1999 planned land use. Scenarios B and C are similar to the 1999 results. Scenario D is slightly lower than the 1999 results.

FIGURE 2
Summary of Predicted In-Lake TP Concentrations by Scenario
Upper Swift Creek Reservoir Watershed Management Plan



Conclusions

The results of each planned land use scenario point to exceeding the TP limit for in-lake concentrations. The next step was to determine the maximum level of annual loading that will result in an in-lake TP concentration of 0.05 mg/L or less. The results of this calculation are in Table 5.

As shown in Table 5, the annual loads required to achieve the in-lake goal vary approximately between 25,000 and 26,000 pounds per year. This variation is due to the relatively similar loads and flows among all scenarios as well as the constant volume and average depth of the reservoir. The last column in the table shows the reduction in the TP

load that is needed to achieve the maximum level of 0.05 mg/L. The analysis indicates that significant reductions are needed.

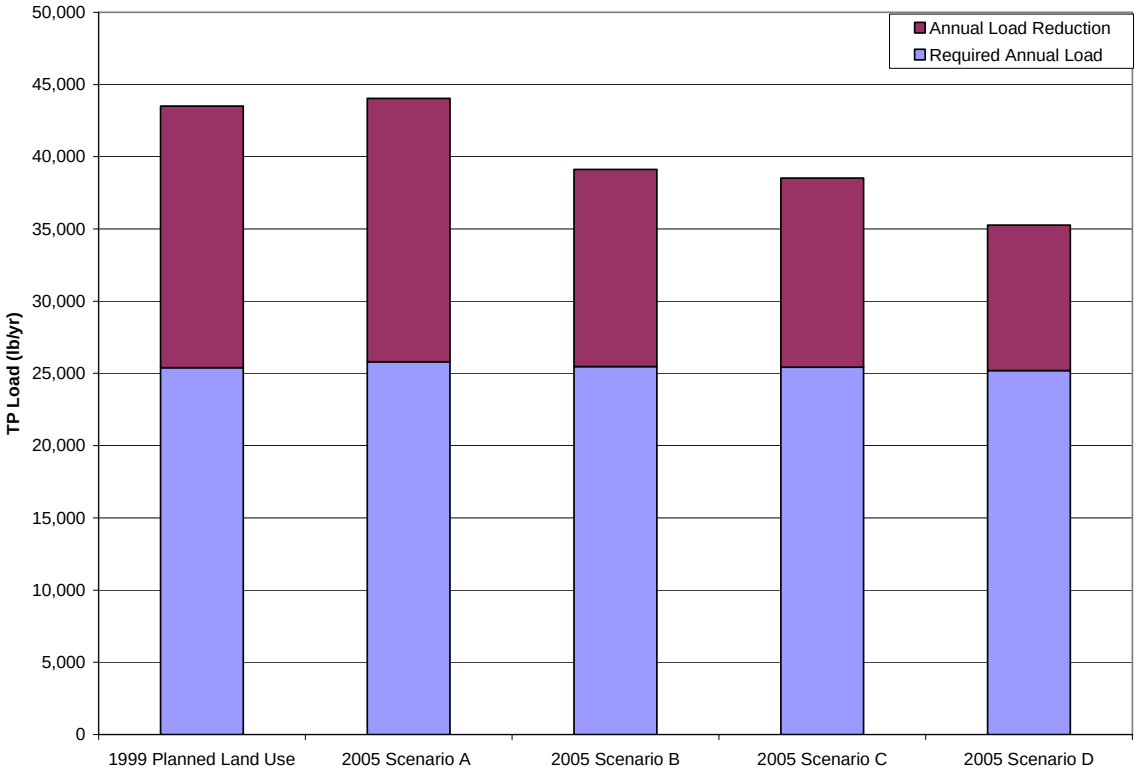
Based on discussions with Planning Department staff, the likely scenario to be recommended for the new land use plan is Scenario B, which is projected to have an annual load of 42,784 pounds per year TP at the planned land use. The modeling results predict that this load will require a reduction of approximately 17,000 pounds of TP per year in order to achieve the in-lake goal. This reduction requirement is 6 percent less than the reduction based on the 1999 planned land use projection (Figure 3).

TABLE 5
Load and Reductions Required to Meet Reservoir Total Phosphorous Limit (0.05 mg/L)
Upper Swift Creek Reservoir Watershed Management Plan

Modeling Scenario	Annual TP Load (lb/yr)	Annual TP Load Required to Achieve 0.05 mg/L (lb/yr)	Reduction Required to Annual Load (lb/yr)
1999 Existing Land Use	12,189	N/A	N/A
2004 Existing Land Use	14,547	N/A	N/A
1999 Planned Land Use	43,508	25,402	18,106
2005 Scenario A Projected Planned Land Use	47,674	26,104	21,570
2005 Scenario B Projected Planned Land Use	42,784	25,767	17,017
2005 Scenario C Projected Planned Land Use	42,181	25,725	16,456
2005 Scenario D Projected Planned Land Use	38,926	25,513	13,413

The increase in impervious TP associated with the new land use CLI results in an increase in more than 4000 pounds of TP per year. As an extra precaution, the County may want to consider additional onsite BMPs for these areas. The onsite BMPs could remove the TP load from imperviousness greater than 55 percent at all future CLI sites.

FIGURE 3
Annual Loads and Required Reductions by Scenario
Upper Swift Creek Reservoir Watershed Management Plan



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Walker, William D., Jr., PhD. 1990. P8 Urban Catchment Model Program Documentation, Version 1.1. May.

Walker, William D., Jr., PhD. 2000. P8 Urban Catchment Model Program, Version 2.4. February.

Appendix A

TABLE A-1
Summary of Previously Modeled Total Phosphorous Annual Loads, by Watershed
Upper Swift Creek Reservoir Watershed Management Plan

Watershed	1999 Existing Land Use (lb/yr)	2004 Existing Land Use (lb/yr)	1999 Projected Planned Land Use (lb/yr)
Little Tomahawk Creek	754	1,270	2,810
Tomahawk Creek	934	1,573	6,138
Swift Creek	3,542	3,163	10,376
Turkey Creek	751	750	2,665
Otterdale Creek	709	1,630	2,933
Horsepen Creek / Deep Creek	1,662	1,566	6,256
Blackman Creek	1,006	1,019	6,021
West Branch	580	742	1,371
Dry Creek	504	904	2,004
Fuqua Creek	415	248	1,010
Direct Runoff Component	1,333	1,682	1,924
Total	12,189	14,547	43,508

TABLE A-2
Summary of Previously Modeled Annual Flows, by Watershed
Upper Swift Creek Reservoir Watershed Management Plan

Watershed	1999 Existing Land Use (ac-ft / yr)	2004 Existing Land Use (ac-ft / yr)	1999 Projected Planned Land Use (ac-ft / yr)
Little Tomahawk Creek	5,415	5,621	6,442
Tomahawk Creek	8,047	8,196	9,873
Swift Creek	24,670	24,546	27,095
Turkey Creek	6,121	6,060	6,732
Otterdale Creek	5,362	5,560	5,963
Horsepen Creek / Deep Creek	7,996	8,021	9,849
Blackman Creek	8,246	8,166	9,522
West Branch	4,290	4,351	4,752

TABLE A-2
Summary of Previously Modeled Annual Flows, by Watershed
Upper Swift Creek Reservoir Watershed Management Plan

Watershed	1999 Existing Land Use (ac-ft / yr)	2004 Existing Land Use (ac-ft / yr)	1999 Projected Planned Land Use (ac-ft / yr)
Dry Creek	4,372	4,548	4,975
Fuqua Creek	3,571	3,567	3,840
Direct Runoff Component	10,805	11,576	11,347
Total	88,894	90,212	100,392

TABLE A-3
Summary of Total Phosphorous Annual Loads by Watershed
Upper Swift Creek Reservoir Watershed Management Plan

Watershed	Scenario A Projected Planned Land Use (lb/yr)	Scenario B Projected Planned Land Use (lb/yr)	Scenario C Projected Planned Land Use (lb/yr)	Scenario D Projected Planned Land Use (lb/yr)	1999 Projected Planned Land Use (lb/yr)
Little Tomahawk Creek	3,030	3,033	3,033	3,026	2,810
Tomahawk Creek	6,348	6,316	6,223	5,722	6,138
Swift Creek	10,632	8,840	8,760	8,334	10,376
Turkey Creek	2,855	1,003	996	938	2,665
Otterdale Creek	4,035	3,281	3,179	2,589	2,933
Horsepen Creek / Deep Creek	8,795	8,628	8,401	7,241	6,256
Blackman Creek	5,888	5,630	5,601	5,448	6,021
West Branch	1,959	1,958	1,947	1,873	1,371
Dry Creek	1,401	1,392	1,365	1,225	2,004
Fuqua Creek	491	489	475	400	1,010
Direct Runoff Component	2,240	2,213	2,201	2,131	1,924
Total	**47,674**	**42,784**	**42,181**	**38,926**	**43,508**

TABLE A-4
Reckhow Model Results
Upper Swift Creek Reservoir Watershed Management Plan

Modeling Scenario	Predicted In Lake TP Concentration (mg/L)
1999 Existing Land Use	0.031
2004 Existing Land Use	0.035
1999 Planned Land Use	0.074
Scenario A	0.078
Scenario B	0.073
Scenario C	0.073
Scenario D	0.069